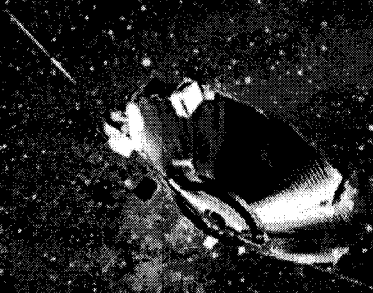


Interstellar Probe using a Solar Sail: Conceptual Design and Technologies



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Potsdam, Germany
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Interstellar Probe Science Objectives

Explore the nature of the interstellar medium and its implication for the origin and evolution of matter in our Galaxy and Universe

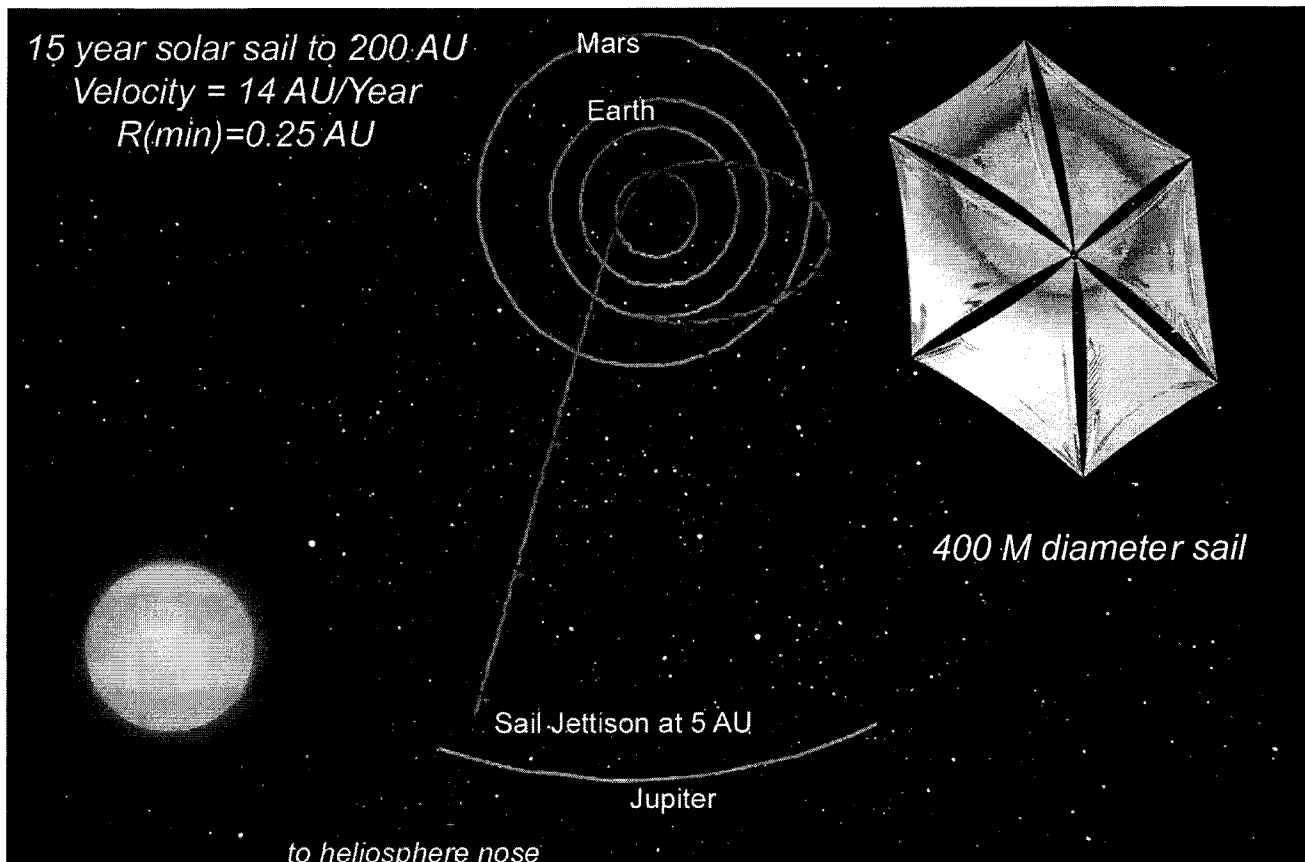
Explore the outer solar system in search of clues to its origin and to the nature of other planetary systems

*Interstellar Probe Trajectory
Earth to 200-400 AU*

Explore the influence of the interstellar medium on the solar system, its dynamics and its evolution

Explore the interaction between the interstellar medium and the solar system as an example of how a star interacts with its local galactic environment

Interstellar Probe using a Solar Sail



Interstellar Probe —Exploring the Interstellar Medium and its Interaction with the Solar System

Status

NASA Science Definition Team -Spring 1999

- Defined Measurements and Objectives
- Defined Requirements & Concept
- Identified Strawman payload & critical technology

JPL Mission Design Team X defined mission concept which meets all mission requirements

In NASA Strategic plan to start in decade beyond 2007



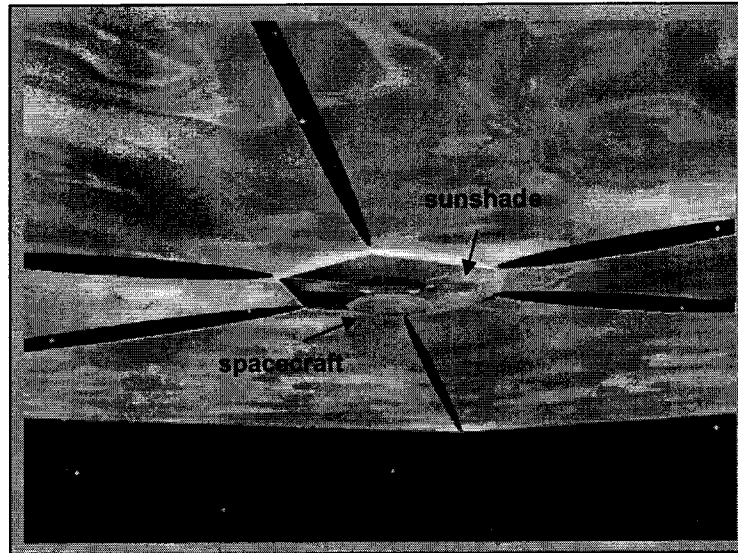
Measurement Strategy

- In situ sampling of dust, plasma, particles & electromagnetic fields of the interstellar medium
- Combine in situ sampling with global energetic neutral atom (ENA) imaging to determine heliosphere structure and dynamics
- Measure the composition of interstellar plasma, neutrals, cosmic rays and dust
- Measure the distribution of interplanetary dust, associated organic matter and zodiacal light emission in the outer solar system
- Look for cosmic infrared background radiation spectrum hidden by zodiacal light at 1 AU

Interstellar Probe Mission Concept

Propulsion & Trajectory

- Send a spacecraft to > 200 AU in < 15 years using solar sail
- Solar sail ~ 200 m in radius
- Aim for nose of the heliosphere
- Sail first to 0.25 AU to increase photon pressure for acceleration to ~ 14 AU/yr
- Jettison sail at 5 AU



Sail Deployment & Control

S/C supported by 3 struts in 11-m hole in sail

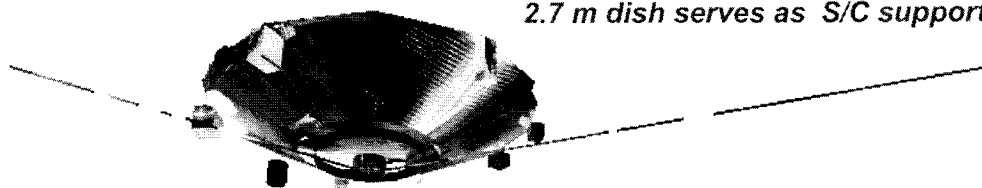
- Deploy using rotation
- Sail packaging, spin up & deployment mechanisms jettisoned after deployment
- Sail & S/C spin stabilized
- Control sail via offset of S/C from sail center of mass

Interstellar Probe Mission Concept

Launch Vehicle: Delta II

Data Strategy:

- Continuous data acquisition at ~ 25 bps
- kA band telecommunications (350 bps@200 AU)
- Store and dump using ~ 1 pass/week
- Higher coverage during occasional "events"



Critical Enabling Technology

- Development and Demonstration of solar sail propulsion
- Solar sails enable many other missions

Scientific Instrument Payload

Stawman Payload

Magnetometer
 Plasma and Radio Wave Sensor
 Solar Wind/Interstellar Plasma/Electron Spectrometer
 Pickup and Interstellar Ion Isotope Spectrometer
 Interstellar Neutral Atom Spectrometer
 Suprathermal Ion/Electron Sensor
 Cosmic Ray H, He, Electron, Positron, γ -Ray Burst Instrument
 Anomalous & Galactic Cosmic Ray Isotope Spectrometer
 Dust Composition Instrument
 Infrared Instrument
 Energetic Neutral Atom (ENA) Imager
 UV Photometer

Additional Candidates

Kuiper Belt Object Detector
 New Concept Molecular Analyzer
 Suprathermal Ion Charge-State Instrument
 Cosmic Ray Antiproton Detector

Resource Requirements

- Mass: 25 kg
- Bit Rate: 25 bps
- Power: 20 W

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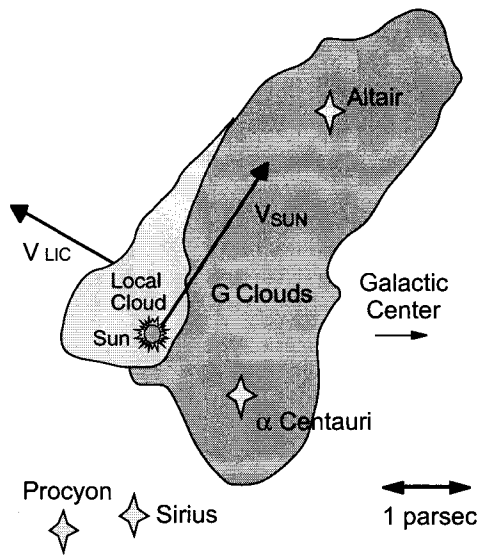
Interstellar Probe Science and Technology Definition Team

Chairman Study Scientist	Richard Mewaldt, California Institute of Technology Paulett Liewer, Jet Propulsion Laboratory	Members
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Program Scientist	Vernon Jones, NASA Headquarters	Priscilla Frisch, University of Chicago
Deputy Program Scientist	James C. Ling, NASA Headquarters	Herbert Funsten, Los Alamos National Laboratory
Program Executive	Glenn H. Mucklow, NASA Headquarters	Mike Gruntman, University of Southern California
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		Renu Malhotra, Lunar and Planetary Institute
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		Thomas Zurbuchen, University of Michigan

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Our Local Galactic Environment



(<0.1 micron), low energy cosmic rays

Sun near edge of our Local Interstellar Cloud (LIC)

$n \sim 0.3$ atoms/cc blowing from Scorpius-Centaurus at 25 km/s relative to Sun

LIC is one of several nearby warm, low density clouds

If Sun entered a typical diffuse cloud of ~ 10 atoms/cc, heliosphere would shrink

Present knowledge of ISM mainly from astronomical observations and dust & neutral atoms which penetrate heliosphere

But remote sensing observations integrate over astronomical lines-of-sights

Heliosphere excludes most charged species: ISM plasma, smaller dust grains

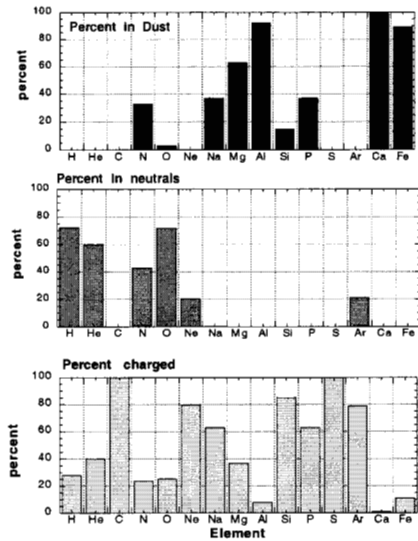
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Interstellar Probe will directly sample ISM free from these uncertainties
A complete sample is obtained because ISP sees matter in gas, plasma and dust

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How does local interstellar matter differ from solar matter?

Theoretical Distribution of Matter among dust, neutrals and plasma in the Interstellar Medium



Model based on current knowledge and reasonable assumptions about ISM (Slavin & Frisch, 1999)

• What is the ionization state of the ISM?

ISP will determine directly how elements are distributed between solid (dust), neutral (gas) and plasma (ionized) states

• What are the elemental and isotopic abundances of the ISM?

Only lightest elements created in Big Bang — others created by nucleosynthesis in stars and latter ejected into interstellar space

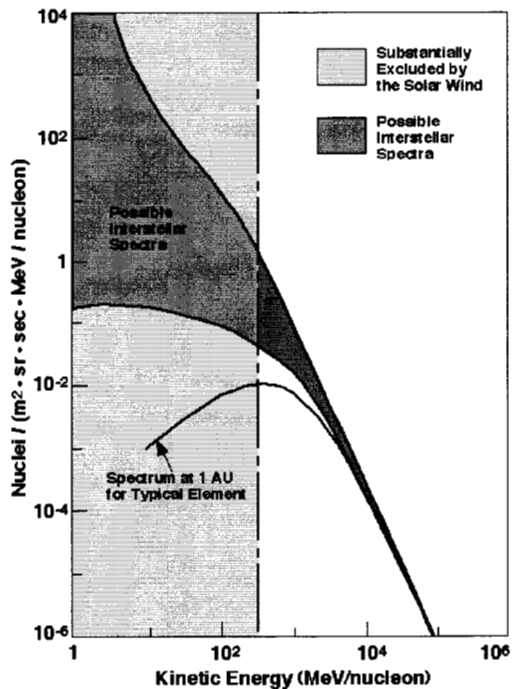
LIC thought to be younger, more "enriched" matter than pre-solar nebula

ISM abundances can compared to solar abundances and those from more distant galactic regions will be used to constrain cosmology and nucleosynthesis models

What will this tell us about the chemical evolution of the galaxy?

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How do Cosmic Rays contribute to energy density of the Galaxy?



Energy spectrum of typical CR nuclei.
CR Intensity at low energies (of both nuclei)

• ISM cosmic ray spectrum unknown

Cosmic ray nuclei with <300 MEV/Nuc excluded from heliosphere by the solar wind & its embedded magnetic field

Cosmic ray electrons also excluded

• ISP measurement of CRs will

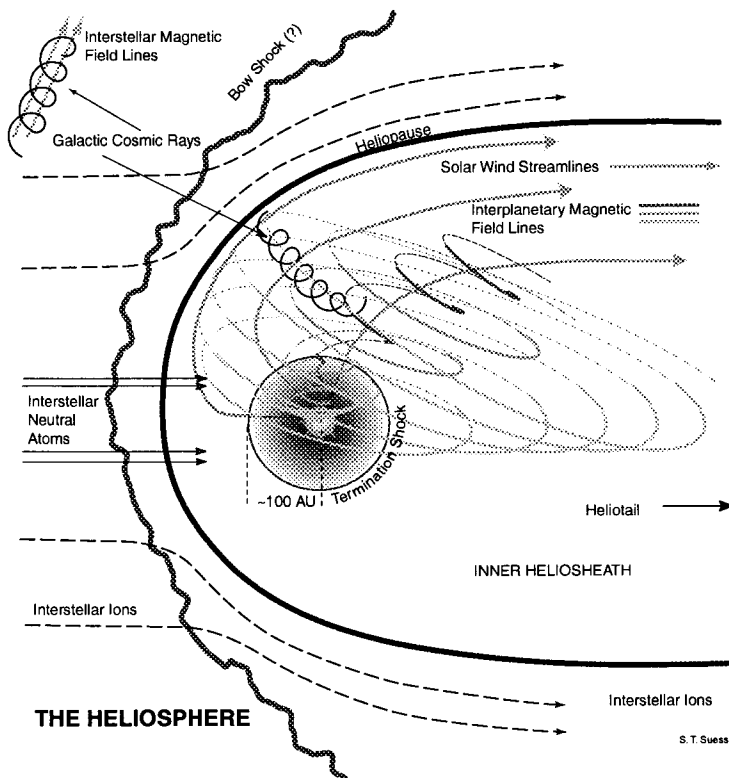
Determine CR energy spectrum and CR contributions to energy density of galaxy and ionization state of ISM

Allow study of astrophysical processes such as CR acceleration by supernova shocks; recent nucleosynthesis & heating of the interstellar medium.

Determine CR Pressure effects on size of heliosphere

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The Global Heliosphere – Created by the Interaction between the Interstellar Medium and the Solar Wind

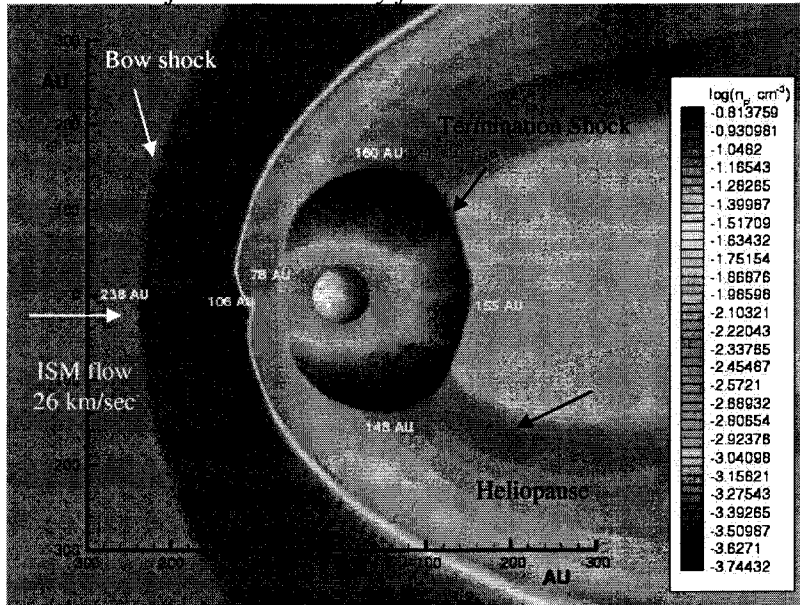


- *ISM flow (~26 km/sec) diverted around heliosphere*
- *Balance of SW ram pressure and unknown pressure from interstellar gas, magnetic fields, and low-energy cosmic rays determines size*
- *Termination shock (TS) – where solar wind makes transition to subsonic flow*
- *No direct measurements of the heliosphere size – TS probably at 80-100 AU and HP at ~150 AU*
- *Voyager 1 at ~76 AU, moving 3 AU/year will establish size of heliosphere but instruments inadequate for key objectives*

What are the Size and Structure of the Global Heliosphere?

Lack of knowledge of interstellar plasma, magnetic field, cosmic rays leads to uncertainty in size and structure of global heliosphere

Contours of Plasma Density from a 3D MHD Model



What is the distance to the heliopause?

What is the nature of the solar wind termination shock?

Is there a bow shock in the ISM ahead of the nose?

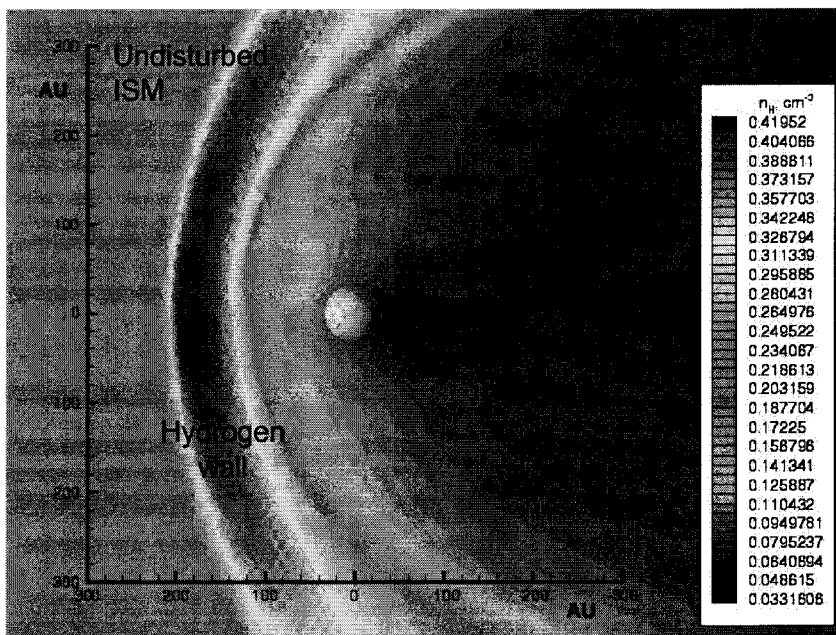
How does the heliosphere respond to variation in the solar wind ram pressure?

Orange - ISM
Blue & Greens - Solar Wind
Red - Shocked ISM
(from T. Linde, thesis)

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Our Heliosphere as an Example of an Astrosphere

The interaction of the interstellar and solar wind plasmas also cause a pile up of neutral hydrogen -- the Hydrogen Wall -- in front of the heliosphere



Neutral Density Contours showing the "hydrogen wall (red)" and the penetration of neutral hydrogen into the heliosphere -- from 3D MHD model (T. Linde, thesis)

ISP will measure the size of our hydrogen wall and calibrate how size depends on solar wind ram pressure

Hydrogen walls have now been observed around many other stars

ISP's calibration can be used to estimate a star's stellar wind from it's observed hydrogen wall

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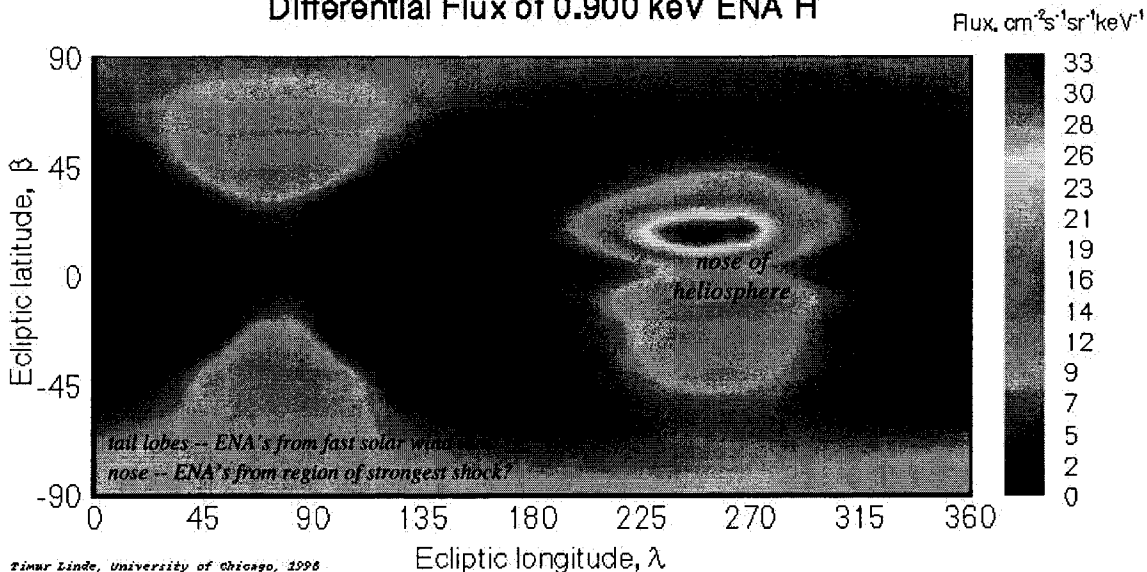
Energetic Neutral Atom (ENA) Imaging of the Heliosphere

Energetic neutral atoms (ENAs), created via charge exchange from hot solar wind ions in the region between the termination shock and the heliopause, can be imaged by Interstellar Probe

These images will reveal information on large scale structure of the heliosphere and the nature and strength of the termination shock

Synthetic ENA image from Earth based on MHD model

Differential Flux of 0.900 keV ENA H



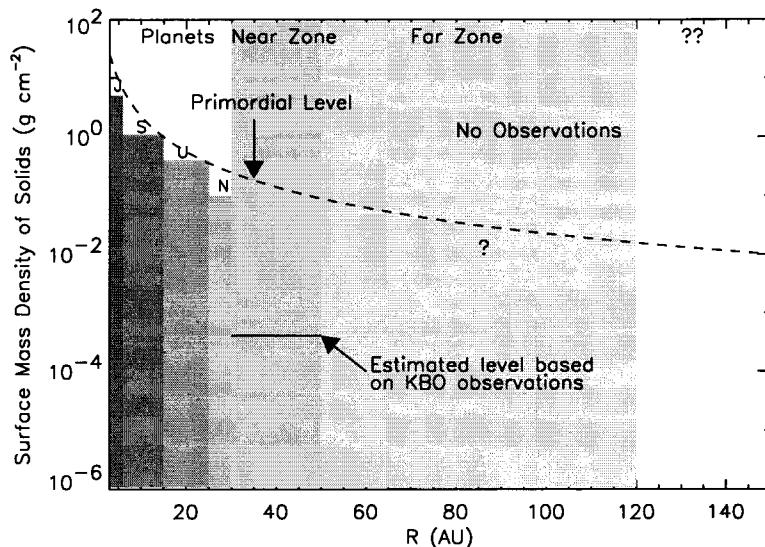
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What is the extent of the Solar Nebula/Kuiper Belt?

Mass density drop beyond 30 AU attributed to collisions with giant planets

*Mass density beyond 50 AU unknown - **No observations***

ISP provides opportunity to study dust and Kuiper Belt objects >50 AU



Mass density in solar system. Primordial level based on mass distribution of planets ($\sim r^{-2}$ and 50% formation efficiency).

Present interplanetary dust is from collisions in the solar system

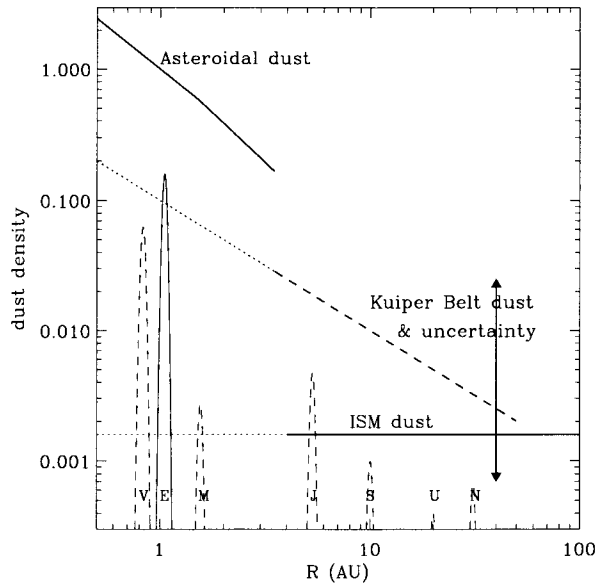
ISP will indirectly determine extent of Kuiper Belt by determining dust density

ISP also may directly survey Kuiper Belt objects > 1km

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Explore our outer solar system in search of clues to its origin and to the nature of other planetary systems

Known (solid) and unknown (dashed) dust

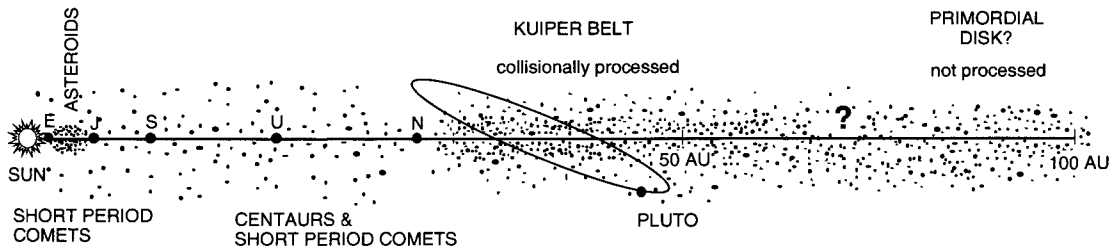


ISP will measure dust structures associated with the planets and the Kuiper belt and constrain models of collisionally processed dust

ISP will determine the structure and composition of the zodiacal dust cloud

ISP will sample dynamically "pristine" primordial disk material > 50 AU

Knowledge of solar dust disk will aid interpretation of dust disk around other stars

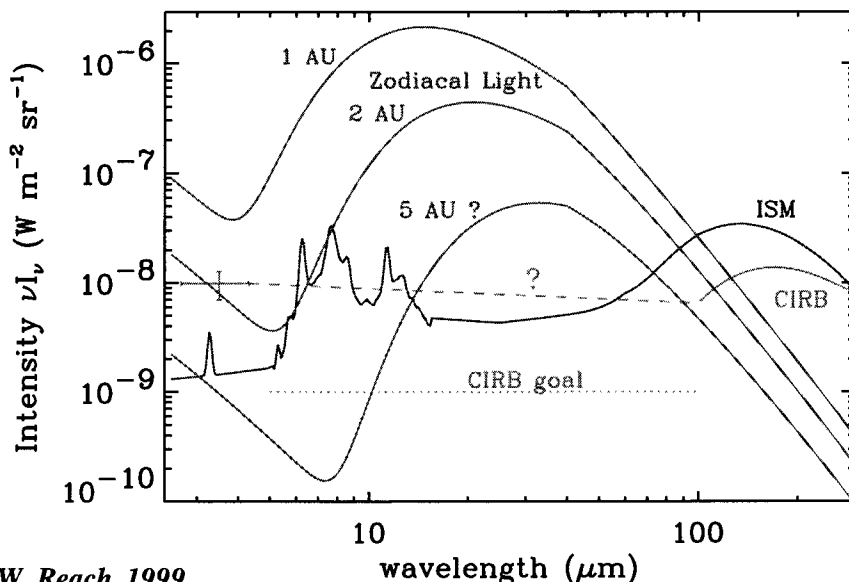


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Interstellar Probe can Observe the Cosmological Infrared Radiation Background without Contamination by Emission from the Zodiacal Dust Cloud

CIRB radiation contains information about the formation and evolutions of the galaxies

Infrared Intensity vs. Wavelength



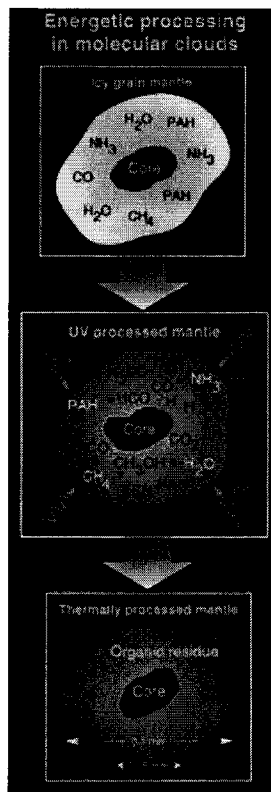
The CIRB has been detected only at >100 and 3 microns

Between 3 and 100 microns, CIRB signal is hidden by that of the Zodiacal Dust

*red--Diffusive ISM - model
Infrared spectrum from
Interstellar medium*

*blue - Zodiacal light at
different distances from
the Sun*

Organic Molecules in the Outer Solar System and ISM



- Organic material is found in both our solar system (in asteroids comets, meteorites, dust) and the interstellar medium
Do these non-terrestrial organic materials have a similar origin?
- Amino acids have been found in meteorites and tentatively identified in ISM in Sagittarius B2
Do they exist in the local ISM?
- Organic material from small bodies is known to reach Earth.
Did they play a role in the emergence of life on our planet?
- ***A suitable instrument on the Interstellar Probe Mission would***
- Search for organic material in the outer solar system and in the nearby ISM
- Determine the nature and chemical evolution of this organic material

Organic material is created in dense molecular clouds on the surface of dust grains which catalyze UV-driven chemistry. Organic residue "glues" grains together, helping to shield molecules from destructive radiation.